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**OPTICALLY SMART SURFACES
SURVIVABILITY TESTING AT MACH 3**

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ABSTRACT

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PREFACE AND ACKNOWLEDGEMENTS

Optically Smart Surfaces for Wind Tunnel Testing is a Small Business Innovative Research (SBIR) Phase II contract that the Aero-Diagnostics Research Section, Experimental Facilities Research Branch, Aeromechanics Division, Flight Dynamics Directorate, Wright Laboratory has with MetroLaser of Irvine, California. This contract requires MetroLaser to develop optically smart sensors for laser velocimetry and boundary layer transition detection that will be demonstrated in a Aeromechanics Division wind tunnel. Due to tunnel scheduling constraints and optical accessibility in the Mach 3 High Reynolds Number Facility a decision was made to test in the Mach 3 HRNF. The question of survivability of optically smart surfaces in the facility needed to be answered early in sensor development so that methods could be changed early if necessary. The Aero-Diagnostics Research Section designed and built a simple wedge model that two optically smart surface plates could be screwed onto for survivability testing. This report is the result of this testing.

Design of the wedge model was completed by Hsue-Fu Lee. The authors wish to acknowledge the facility support provided by Max Hillsamer, Tom Norris, Rick Allen, SSgt John Williams, and Joe Scheuring. Mr. Ed Fields of the Technical Photo Division provided superb support in photographing the model and smart surfaces. Dr. James Trolinger, Dr. James Millerd, and Mr. Fred Unterseher are the principle players in the project at MetroLaser.

INTRODUCTION

Optically Smart Surfaces for Wind Tunnel Testing is a program for development of the technology to embed holographic optical elements on the surface of a wind tunnel model which will be used for laser velocimetry, strain, or boundary-layer transition detection. Further details on this technology have been reported by Trolinger and Rosenthal (1992a and 1992b). A holographic optical element is a hologram that is used to simulate a conventional optical element. The emulsion used on the aluminum plates was photoresist as described by Trolinger and Rosenthal (1992a).

However, if optically smart surfaces are to be utilized in supersonic high-Reynolds number flows, the emulsion they are constructed on must be able to survive the harsh environments that can be encountered in these facilities. Hence, the purpose of these survivability tests was to determine if photoresist could withstand the environment of the Mach 3 High Reynolds Number Facility (HRNF) at the Wright Laboratory.

TEST DESCRIPTION AND RESULTS

The optically smart surfaces wedge shown in Figs. 1 and 2 was tested in the Wright Laboratory Mach 3 HRNF. The 15 degree wedge was designed with two indented areas for mounting 4 inch by 5 inch aluminum plates with optically smart surfaces. The plates are mounted such that one plate is parallel to the freestream velocity and the other plate is mounted at a 15 degree angle of attack relative to the freestream velocity. Operating conditions for the Mach 3 HRNF were published by Fiore, et al (1975).

For this set of experiments the tunnel was operated at stagnation pressures of 85, 150, and 300 psia which corresponds to a Reynolds number range of 14.9 to 52.6 million/ft at a stagnation temperature of 500°R. The static temperature at these conditions is around 150°R and thus the tunnel and model begin collecting frost upon tunnel shutdown. A summary of the test

runs and their conditions is shown in Table I. It should be noted that for run 1 the tunnel had not been operated for a period of approximately 12 months and a thin layer of rust had formed of the tunnel sidewalls. This resulted in the first run having a large content of abrasive particles present in the freestream flowfield. This was considered the worst case scenario that might be encountered by the optically smart surfaces. The holographic optical elements on the optically smart surfaces prior to wind tunnel exposure are shown in Fig. 3.

During run 1, the optically smart surfaces parallel to the freestream flow survived the abrasive flowfield satisfactorily. However, the surface at the 15 degree angle of attack was essentially sand-blasted to the base aluminum surface in a period of approximately 2 seconds. The streamlines for $3.6\text{ }\mu\text{m}$ alcohol particles over a 10 degree half-angle wedge in the Mach 3 facility as computed by Maurice (1992) are shown in Fig. 4. It is believed that the particles impinging on the optically smart surfaces were on the order of $10\text{ }\mu\text{m}$ in diameter and thus would impact the model further from the leading edge and be entrained in the boundary layer.

Prior to the second run, the model was heated to the point where water vapor was no longer freezing on the model surface and the plate that survived run 1 was moved to the 15° angle of attack position for the remaining runs. Run 2 was begun at a stagnation pressure of 85 psia for 45 seconds. Little or no visible deterioration of the smart surfaces took place at that condition. Then the tunnel stagnation pressure was increased on-line to 150 psia and held at that condition for approximately 30 seconds. Again no visible deterioration took place. Finally, the stagnation pressure was increased to 300 psia. At this condition the surface began deteriorating immediately and after 15 seconds the surface had been essentially sand-blasted to the base aluminum.

Table I: Test Conditions

Run No.	Plate	Plate Angle of Attack (degrees)	Stagnation Pressure (psia)	Reynolds Number	Run Duration (seconds)
1	1	15	150	$26.3 \times 10^6/\text{ft}$	55
1	2	0	150	$26.3 \times 10^6/\text{ft}$	55
2a	2	15	85	$14.9 \times 10^6/\text{ft}$	45
2b	2	15	150	$26.3 \times 10^6/\text{ft}$	30
2c	2	15	300	$52.6 \times 10^6/\text{ft}$	15

CONCLUSIONS AND RECOMMENDATIONS

The conclusion of this series of testing is that the survivability of holograms in the Mach 3 facility depends upon the Reynolds number and the angle of attack. The optically smart surface holograms survive at 0° angle of attack for Reynolds numbers up to at least $26.3 \times 10^6/\text{ft}$ and additional testing would be required to determine if they survive at higher Reynolds numbers. However, it is the opinion of the authors that the specific type of surfaces tested would survive at any Reynolds number at 0° angle of attack. At 15° angle of attack, these surfaces survived the "clean" flow up to Reynolds number of $26.3 \times 10^6/\text{ft}$. At higher Reynolds

numbers the particle impingement on the surface essentially sand blasted these surfaces making them unusable for measurements. These particular surfaces at angle of attack will not survive the "dirty" flowfield of a wind tunnel that has not been operated for any significant period of time.

The results of these tests lead to the recommendations that this optically smart surface material would only be usable in high-Reynolds-number flowfields at 0° angle of attack. In the interest of demonstrating the functionality of optically smart surfaces, it is recommended that initial testing at the Wright Laboratory take place in the Trisonic Gasdynamics Facility at a Mach number in the range 0.3-0.8. Additional research and development of rugged optically smart surfaces will continue.

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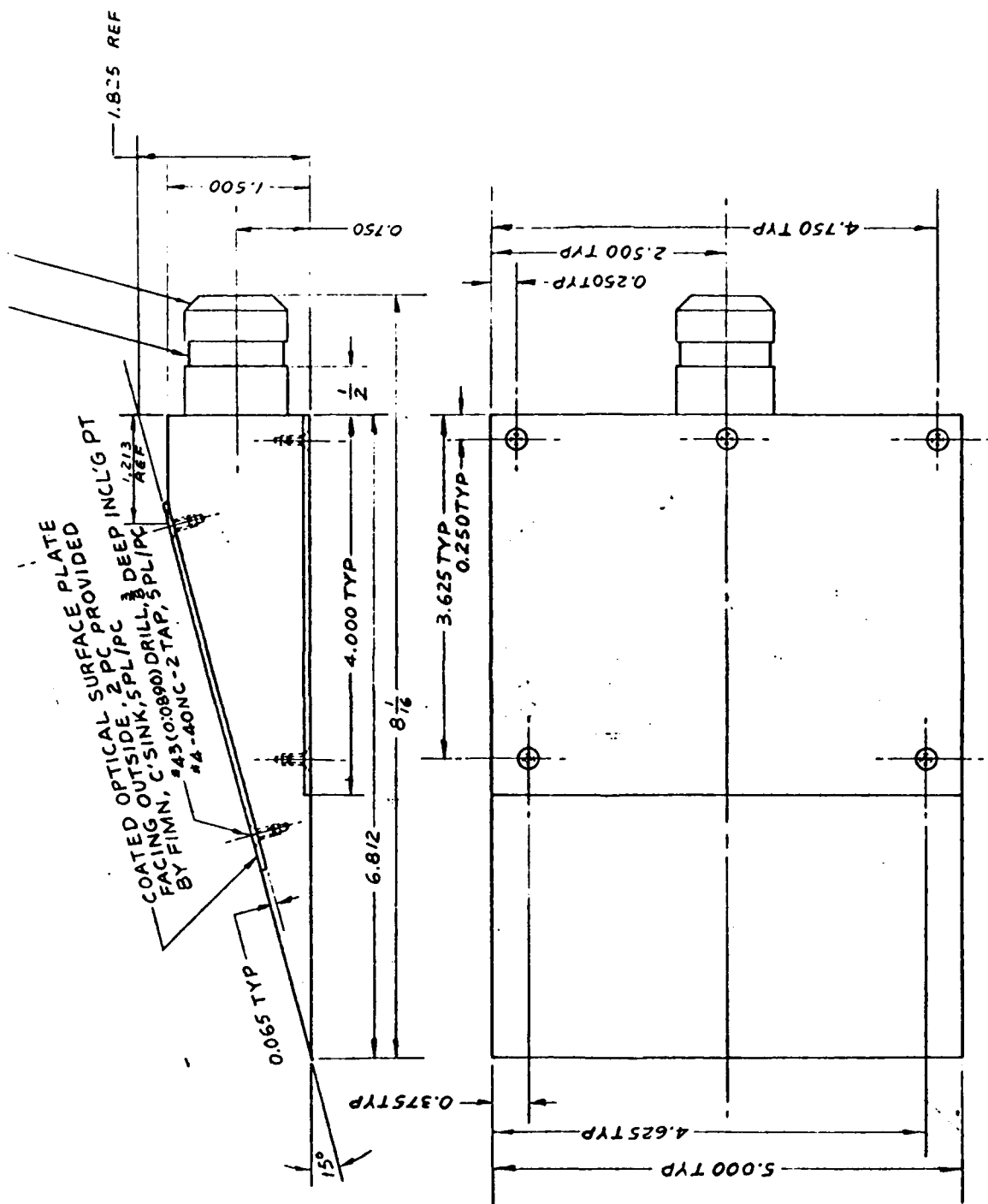


Fig. 1. Optically Smart Surfaces Wedge Technical Drawing.



Fig. 2. Optically Smart Surfaces Wedge.

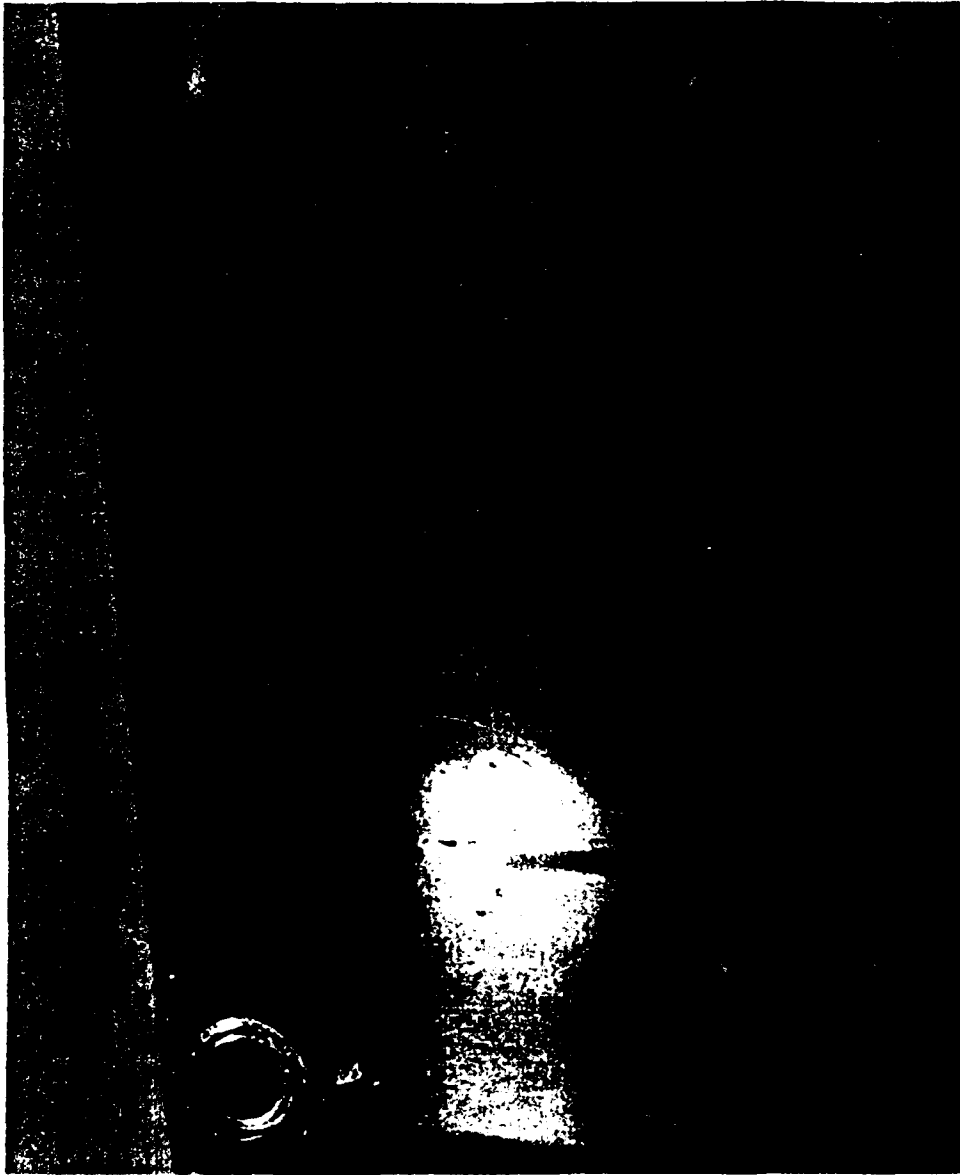


Fig. 3. Optically Smart Surfaces Prior to Wind Tunnel Testing.

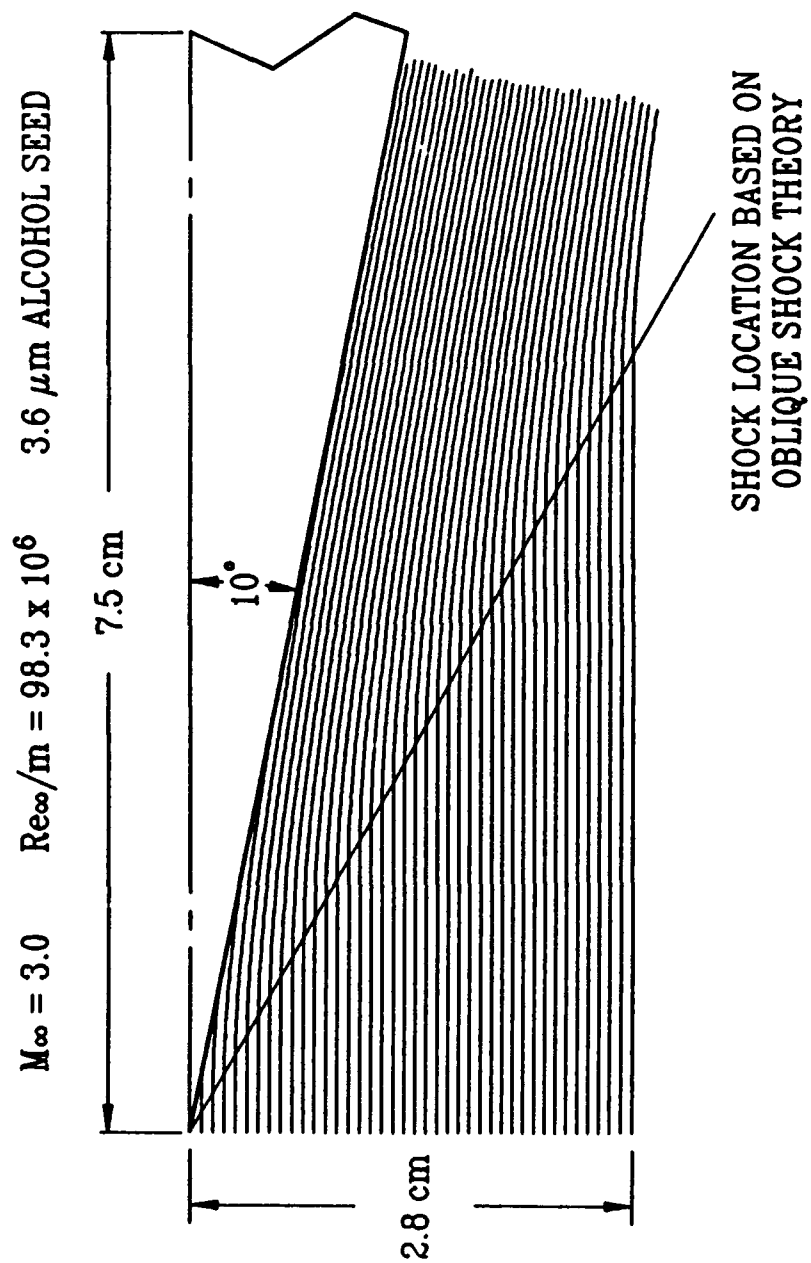


Fig. 4. Particle Streamlines on a 10° Half-Angle Wedge at Mach 3.